IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
Group Art Unit 3746

In re

Patent Application of

Robert M. Koehl

Application No. 10/730,747

Confirmation No. 2653

Filed: December 8, 2003

Examiner: Emmanuel Sayoc

"PUMP CONTROL SYSTEM AND METHOD"

I, Raye L. Daugherty, hereby certify that this correspondence is being deposited with the U.S. Postal Service as first class mail in an envelope addressed to Mail Stop Amendment, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on the date of my signature.

Raye Lynn Daugherty
Signature

3-14-06
Date of Signature

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION OF PRIOR INVENTION TO OVERCOME CITED PATENT (37 C.F.R. §1.131)

Sir:

Applicant respectfully requests consideration of the following declaration filed in connection with the above-referenced application and on even date with the filing of a paper entitled Amendment.

PURPOSE OF DECLARATION

This declaration is submitted to establish conception and reduction to practice of the invention in the United States before October 28, 2003 (the filing date of U.S. Patent No. 6,925,823 in the name of Lifson et al., hereinafter "the Lifson et al. patent").

SUPPORTING FACTS AND DOCUMENTARY EVIDENCE

1. The Lifson et al. patent was cited in rejections under 35 U.S.C. § 103(a) in a December 14, 2005 Office action issued with respect to the above-referenced application.

2. The person making this declaration is the sole inventor of the subject matter in the above-referenced application.

3. The Applicant conceived of the invention in the above-referenced application before the October 28, 2003 filing date of the Lifson et al. patent.

4. Applicant exercised due diligence from the conception date of the invention until the invention was reduced to practice all of which occurred before the December 8, 2003 filing date of the above-referenced application.

5. To establish the conception and reduction to practice of the invention as claimed in the above-identified application, the following attached documents, entitled "Sta-Rite – High Speed Motor Controller, Hardware Design Specification, Revision H" and "STA-RITE High Speed Motor Controller, Description of Software Features, Version H" are submitted as evidence. The attached documents were made before the October 28, 2003 filing date of the Lifson et al. patent.

6. The attached documents, which support the claims in the above-identified application, clearly evidence conception and reduction to practice of the invention before October 28, 2003. Applicant directs the Examiner's attention to Section 3.4 on page 21 of the document entitled STA-RITE High Speed Motor Controller, Description of Software Features, Version H.

7. This declaration is timely submitted in the above-referenced application before a final rejection.

8. As a person signing below:

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of inventor: ~~Robert~~ M. Koehl

Inventor's signature: Kyle M. Koehl Date: February 28, 2006

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DESIGN

Sta-Rite - High Speed Motor Controller

Hardware Design Specification
Revision H

APPROVALS		
		SMTC Design
Name		**Michael Cerny** Director – Design Engineering
Date		
Name		
Date		

Revision History

Initials	Date	Description	Rev
JT		Initial Internal Release	A
GDP		Second Internal Release	B
GDP		Changes from meeting on 9-18-2000	C
GDP		Reduction of maximum ambient temperature	D
RJK		Added pressure sensor connection Added selectable V/Hz slope selection Added Voltage Surge Protection Added the option for multiple boards Updated input and output current levels Added three fault conditions Added that efficiency will change with cable length Changed reset interface	E
RJK		Added Rev F because of two different Rev E's	F
TVS		Clarified Specs	G
RWZ		Changed CISPR11 to CISPR 14	H

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1.0 APPLICABLE DOCUMENTS

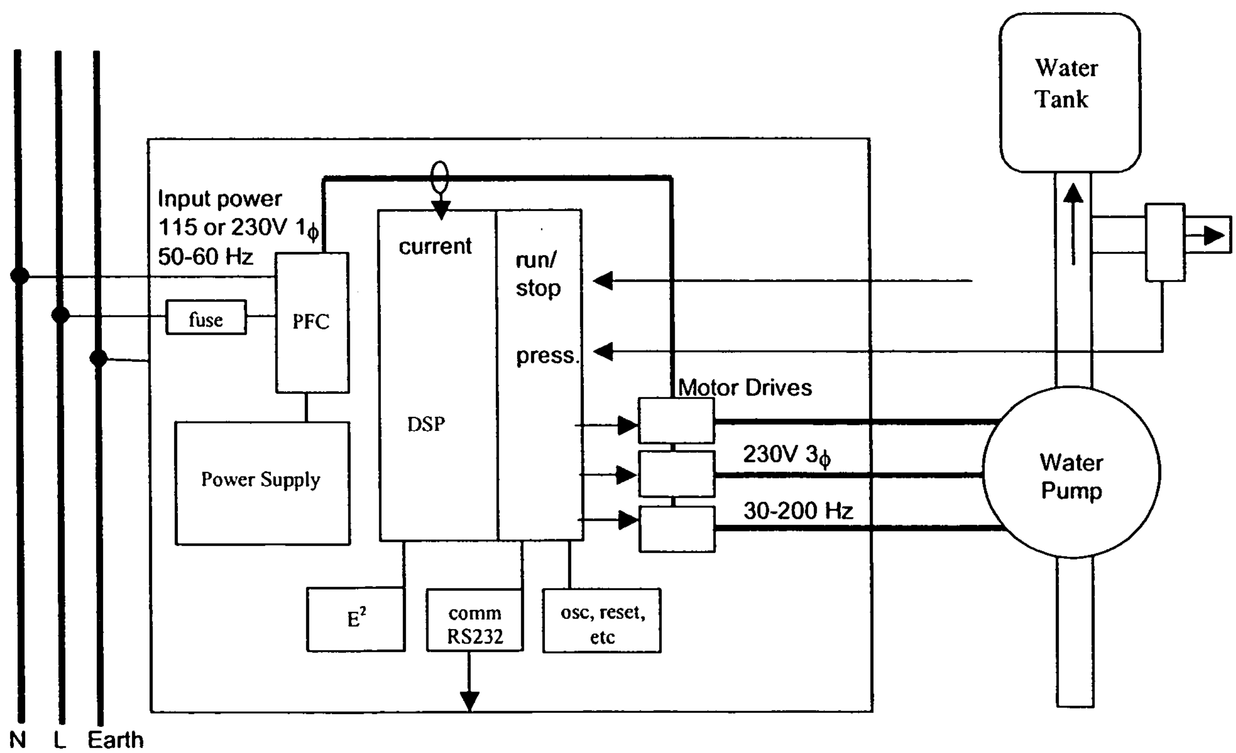
Sta-Rite Industries – "High Speed Motor Electronics", R. Koehl, 3/20/00

"Sta-Rite High Speed Motor Controller, Description of Software Features" Version F

2.0 PRODUCT OVERVIEW

The Sta-Rite High Speed Motor Controller (HSMC) is a circuit used to control the operation of a water pump. The typical application is a residential or commercial water supply pump system. The circuit will monitor certain operating parameters and control the operation of the pump motor in response to the sensed conditions. The circuit shall make use of a digital signal processor (DSP) to perform real time control including soft-start, speed regulation, and motor protection.

2.1 Block Diagram



2.2 *Product Features*

The following is a list of the main features of the High Speed Motor Controller:

- 115 or 230 V_{RMS} (production build option), 50-60Hz, single phase input power
- Integral input fuse
- Power factor correction
- Output choice #1: 0 -230 V_{RMS} (L-L), 30 -200Hz (capability – not tested)
- Output choice #2: 0 -230 V_{RMS} (L-L), 30 -60Hz (capability – not tested)
- Output choice #3: 0 -230 V_{RMS} (L-L), 30 -80Hz
- Pressure feedback
- Soft start of motor
- Output current limited
- 88% or better efficiency @ rated output
- Protection for current, voltage, temperature, and rapid load cycling
- Non-volatile storage of faults and configuration parameters
- Flash application memory
- Auto shut down w/ manual reset (cycle power)
- Communication port
- Rugged, rain-proof enclosure
- 12 awg power wiring connectors
- Voltage Surge Protection

3.0 GENERAL REQUIREMENTS

3.1 *Environmental*

Operating Temperature Range (Ambient temperature outside enclosure and drive under full load)	-20°C to +55°C (Different ambient temperature and power rating combinations may need different heat sink options)
Storage Temperature Range	-40°C to +85°C
Operating Humidity Range	10 to 90% RH Non-condensing
Operating Altitude Range	Sea level to 10,000 ft.
Ventilation Provision	Convection air movement only.
Vibration	IEC68-2-6, 1G@40-150Hz, 0.012in p-p at 10-40Hz

Shock	IEC68-2-27, 15G, 11ms
Weather Resistance (enclosure)	NEMA-4
Immersion	Not required
Flammability	PCB Material UL-94V0, Components UL recognized as needed.
ESD Immunity	EN61000-4-2, (LEVEL 3), self-recovering with no hard failures. Additionally, no loss or corruption of stored data may occur during test.
RF Susceptibility	EN61000-4-3, (LEVEL 2), self-recovering with no hard failures. Additionally, no loss or corruption of stored data may occur during test.
Fast Transient Susceptibility	EN61000-4-4 (LEVEL 2), self-recovering with no hard failures. Additionally, no loss or corruption of stored data may occur during test.
Electrical Surge Susceptibility	EN61000-4-5 (LEVEL 3), self-recovering with no hard failures. No loss or corruption of stored data may occur during tests.
Conducted Susceptibility	EN61000-4-6 (LEVEL 2). No loss or corruption of stored data may occur during test.
Voltage variations immunity	EN61000-4-11. Voltage variations testing. No loss or corruption of stored data may occur during test.

3.2 *Agency Approvals* - CE Mark *Compliant*

Safety (Low Voltage Directive)	IEC/EN60730-1 UL/cUL 508C
EMC Directive and FCC compliance	EN61000-3-2 Harmonics EN61000-3-3 Flicker FCC Part 15, Subpart B Class B EN55014 (CISPR14) IEC/EN50081-1 and IEC/EN50082-1

3.3 Physical

PCB Configuration	Two boards measuring less than 8 inches x 10.5 inches
Conformal Coat	As Required
Potting	Not Required

3.4 Electrical

Input Fusing	Integral fuse required, 115 V_{RMS}: 30 A_{RMS} 230 V_{RMS}: 15 A_{RMS}
Input Power	103 to 127 V_{RMS} single phase: < 30 A_{RMS} 207 to 253 V_{RMS} single phase: < 15 A_{RMS}
Input Frequency	45 to 65 Hz
Power Efficiency	88% or better over-all efficiency at rated output power when connected to motor with 3meters of 12-3 W.G. NM-B
Power Factor	≥ 0.98 at rated output power
Output Power (rated)	2116W max (230V @ 9.2A_{rms} total) 250 V_{RMS} max phase-to-phase 5.9 A_{RMS} max per phase (Different ambient temperature and power rating combinations may need different heat sink options)
Output Drive Frequency	1 to 200 Hz
PWM Switching Frequency	7.2 kHz +-1%

	defined in 5.4 Status Indicators.
Run Indicator	LED (Green) under control of firmware, operation defined in 5.4 Status Indicators.

5.0 FUNCTIONAL REQUIREMENTS

5.1 Normal Operation

The controller stands idle until the pressure in the system drops below a preset value. The controller then increases or decreases the speed of the motor to maintain the constant pressure set point.

5.2 Configuration / Installation

The performance of the controller can be optimized for many different operating conditions. The following can be configured with the rotary switches:

Desired water pressure: 25 – 95psi
User defined, 30 – 60 Hz, 30 – 80 Hz, or 30 – 200 Hz V/Hz slope selection

Installation would include the following steps:

Configure the rotary switch settings
Connect the pressure feedback
Connect Run/Stop terminals to external switches as needed (drive will not run without the Run/Stop terminals shorted)
Connect the motor leads
Connect chassis to earth ground
Connect line power (115 V_{RMS} or 230 V_{RMS} single phase; option based)

5.3 Faults

The controller will be able to detect certain problems and possibly prevent damage to itself or the motor. The table below describes the faults, under what conditions they occur, and what actions are taken after sensing the fault.

Fault	Condition	Action Taken
Over Voltage	Bus voltage is greater than the high bus limit	Stop driving motor
Under Voltage	Bus voltage is less than the low bus limit	Stop driving motor
Over Current	Bus current is greater than max. current setting	Stop driving motor
Under Current (Dry running)	Bus current is less than expected for a particular speed.	Stop driving motor
Over Temperature	Temperature of heat sink is greater than setpoint (This may change based on Agency requirements, or best cost solution)	Stop driving motor
Foreign Object Jamming Pump	Over current detection occurs five times within 5 minutes.	Reverse direction of rotation
Pressure Sensor open	Signal from pressure sensor outside sense range (High side)	Stop driving motor
Pressure Sensor shorted	Signal from pressure sensor outside sense range (Low side)	Stop driving motor
Output Short-Circuit	Line to Line Short-Circuit Line to Ground Short-Circuit	Stop driving motor

After any fault that stops the motor, the controller will wait 30 seconds and then restart. After a limited number of faults, the controller will shutdown until power is cycled.

5.4 *Status Indicators*

Two LEDs (one red, one green) will indicate the status of the controller. The green Run Indicator is used for normal operation. The red Fault Indicator will blink when a fault has been detected and remains blinking even if the fault has been automatically cleared by the system. The reset button can be used to clear the red Fault Indicator. Different classes of faults are indicated by different blink rates.

5.5 *Communications Interface*

The Remote Terminal Interface will use a standard DB-9 connector (RS-232, DCE, 3 wire). Communications can be achieved with a typical PC using HyperTerminal. The following commands are some of those implemented.

DATA	Display the following information, continuously updated: status, water pressure, speed, bus voltage, bus current, power, total operating hours.
DCPS	Parameters of the controller are shown.
GFLT	Faults from the complete history of the controller are shown.
GVER	Version of software being used is shown.
RCMD	Run in normal operation.
STOP	Stop.

STA-RITE High Speed Motor Controller Description of Software Features

Version H

Submitted By: Trevor Laak, et. al.

Overview

The STA-RITE High Speed Motor Controller (HSMC) is used to control the operation of an AC induction motor that drives a water pump. The typical application is a residential or commercial well pump system. The software runs on a digital signal processor (DSP) and performs real time control including soft-start, speed regulation, and motor protection.

Revision History

Rev	Section	Description	Date	Author
A	ALL	Initial design definition.		TAL, DLH
B	ALL	Update document based upon customer feedback and changes to hardware design. Added software controlled PFC section. Added external microcontroller section. Added new scope items.		DLH
C	ALL	Added/Modified commands for custom V/Hz curve. Added commands for Auxiliary Relay. Removed software controlled PFC section. Improved internal document formatting.		EGB
D	Cover Page, Header, Section 3	Modified document to reflect next generation of design. Significant changes to content and format.		PDM
E	3.3.4, 3.5.6	Updated Sections.		TAL
F	3.3.1 3.3.2 3.2.6 3.1.2 3.1.12 3.4 3.5 (now 3.4)	Updated Section. Added Section. Updated Section. Updated Section. Updated Table. Removed Section (replaced by 3.3.2) Updated Section.		TAL TAL EGB EGB EGB EGB EGB
G	3.1.13.2 3.6.1 3.5	Corrected table entries for DOPD, GRTM, SDRT and SVOV. Corrected fault code categories. Updated fault code table.		EGB EGB EGB
H	3.5 3.1.12	Updated fault code table and fault descriptions. Added default values to EEPROM table		EGB PDM

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1.0 Scope

The STA-RITE High Speed Motor Controller (HSMC) is used to control the operation of an AC induction motor that drives a water pump. The typical application is a residential or commercial well pump system. The software runs on a digital signal processor (DSP) and performs real time control including soft-start, speed regulation, and motor protection.

The overall goal of this AC Induction motor control system is to maintain a constant water pressure in a pump/tank/distribution system. To meet this goal, a classical Proportional/Integral (PI) controller will be implemented that uses the pressure error as the input. Pressure error is calculated by subtracting the actual water pressure from the desired water pressure. The output is an updated speed control command and is generated by multiplying the pressure error by a proportional gain, multiplying the integral of the pressure error by an integral gain, and summing the results.

2.0 Reference Documents

- High Speed Motor Electronics Document (STA-RITE)
- AC Induction Motor Control Using Constant V/Hz Principle and Space Vector PWM Technique with TMS320C240, Application Report SPRA284A, by Zhenyu Yu and David Figoli (TI DSP Digital Control System Applications)
- STA-RITE – High Speed Motor Controller Hardware Design Specification (SMTC)
- Performance Criteria Laboratory Investigation for STA-RITE High Speed Controller, (SMTC)
- Performance Testing of Franklin Drive at STA-RITE Facility, (SMTC)
- STA-RITE PIC Firmware Architecture (SMTC)

3.0 General Description

This design is basically a power conditioner, a variable speed drive and pressure regulator for a pump assembly typically used in a residential well. It is built around two processors working in cooperation. There is a DSP for managing overall system operations and an 8-bit controller acting as a smart sensor. The 8-bit controller is on an isolated ground plane and communicates to the DSP via an optically isolated asynchronous channel as detailed later in this document. The array of sensors and outputs used in this design are also described in the following sections. That array includes an analog pressure sensor attached to the output of the well pressure tank and is used to monitor the water pressure in the residence.

The software control system stands idle until the pressure in the system drops below a preset value. The controller then increases or decreases the speed of the motor to maintain the constant pressure setpoint. The motor speed is controlled via a classical PI control loop using the difference between the actual water pressure and the desired pressure in order to maintain the constant pressure setpoint in the system. When the water pressure in the system exceeds the constant pressure setpoint, the controller will stop driving the motor after a predetermined increase in pressure above the constant pressure setpoint.

3.1 I/O Directly Managed at the DSP

The DSP reads several analog and digital input signals directly. It also is in control of some digital, or on/off style, outputs. All signal filtering and processing happens at the DSP regardless of where that data is gathered.

The ADC sequencer on the DSP reads several analog channels during every conversion period. The ADC sequencer is reset just before the hardware triggers a new SOC (Start of Conversion). This allows the software to maintain uniform channel sample rates. In addition, certain analog channels are read at a fixed interval by the PIC16LF870 and that raw data is sent to the DSP, via a serial port, for processing. To facilitate filtering, the minimum sample rates are determined to be 8 times the input's maximum frequency.

3.1.1 Bus Voltage

Bus voltage is used to halt motor operation during an over-voltage or under-voltage condition. A low bus voltage, but above the under-voltage shutdown level, can put the drive into a limp mode. The maximum frequency of this input is 280 Hz, so the minimum sample rate is 2,240 Hz. Target bus voltage is 380 VDC.

3.1.2 Line Voltage

Line voltage is monitored to help determine the power (VA) being supplied to the drive. The maximum frequency of this input is 65 Hz; the minimum sample rate is 520 Hz.

3.1.3 Line Current

Line current is monitored to help determine the power (VA) being supplied to the drive. Line current is also used to put the drive into a limp mode if the line current exceeds the programmed threshold. The maximum frequency of this input is 65 Hz; the minimum sample rate is 520 Hz.

3.1.4 Reference Voltage

Reference Voltage is used to calculate an offset value for the DSP managed analog inputs. Theoretically, this voltage should be one-half of the DC rail voltage for the active filters that process the signal. However, due to part tolerances, temperature and age, this value can vary slightly over time. Hence, this value is measured to account for any variances. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz.

3.1.5 Pressure Level Set Point Switch

The Pressure Level Switch can be used to set the desired water pressure set point. Since the pressure level switch has 16 positions, the pressure settings range from 25 to 95 PSI in 5-PSI increments. If the switch is in position zero the pressure set point used by the control software is loaded over the serial interface and recovered from the EEPROM at power up.

3.1.6 Motor Select Switch

The Motor Select Switch can optionally be used to configure the drive for the proper motor type. The switch is an 8-position rotary switch and has three digital output lines.

The motor select switch is used to select three sets of factory defaults for three specific motor types (selections 1,2,3). It is also used to select one custom motor type (selection 0). The position of this switch selects the corresponding Volts-Hertz (V/Hz) curve, voltage, current and power limit for a given motor design. At the time of development only motor selection 2 was supported, and that V/Hz curve was estimated. No data on the other two motors was available from STA-RITE. Likewise if the custom motor type is selected it is the responsibility of the user to set the V/Hz curve and protection limits to correspond with the motor under test.

The switch positions and their corresponding motor type are defined as follows:

0 – custom motor	(user must manually configure drive for motor)
1 – 30 to 60 Hz motor	(theoretical motor, untested motor data loaded)
2 – 30 to 80 Hz motor	(V/Hz curve estimated by SMTC, TBD by STA-RITE)
3 – 30 to 200 Hz motor	(theoretical motor, untested motor data loaded)
4,5, 6 or 7 – invalid	(no motor data loaded)

3.1.7 Status Indicator LEDs

There are two LEDs that indicate the status of the drive.

3.1.7.1 LED Flash Rates

The status indicator LED is flashed at various rates to indicate current drive status.

Three flash rates are defined by the following patterns:

- SLOW - LED turned on for 2 seconds, off for 1 second.
- FAST - LED turned on for 0.2 seconds, off for 2 seconds.
- COMBINATION - LED turned on for 0.2 seconds, off for 0.5 seconds, on for 1 second, off for 0.5 seconds.

3.1.7.2 Green LED

The Green LED is on solid when power is applied and the controller is NOT driving the motor. When the controller is driving the motor, and it is NOT in any "Limp" mode, the Green LED flashes at the SLOW rate. However, if the controller is driving the motor in any "Limp" mode, the Green LED flashes at the FAST rate.

Note: The Green LED blinks at a 50% duty cycle during the power-up delay (approximately 30 seconds).

3.1.7.3 Red LED

The Red LED is used to indicate faults. It is off when no faults have occurred since the last reset (or since faults were last cleared). If a fault occurs, then this LED flashes at a certain rate based on the type of fault. It continues to flash at this rate until a fault of a different type occurs, or until the Clear Faults button is pressed. The LED is full on if 15 faults occur within any 15-minute window. A Clear Faults button press halts the flashing until another fault occurs.

The flash rate is only intended to give a general class of fault. It is not intended to indicate specific faults. The various flash rates, based on the fault type, are outlined in the Fault Handling and Logging section later in this document.

3.1.8 Clear Fault LED Button

This input is a normally open push button contact. When the push button contact is closed, the software halts the flashing of the fault LED. No faults are cleared and the fault log is not erased.

3.1.9 Auxiliary Relay

This output is programmable. If enabled it will report the state of the motor and be closed whenever the controller is driving the pump motor. Otherwise, this output is off. This relay can be enabled/disabled via serial command. The minimum time the relay is energized before de-energized is programmable via the serial channel as minimum on time. Likewise the minimum time the relay must be de-energized before it is allow to turn back on is also programmable. Finally, the time that the motor must be off before the relay is allowed to de-energize is also programmable via serial commands.

3.1.10 PFC Control

There are two digital outputs associated with the PFC hardware. One selects the target DC bus voltage (350 or 380 VDC only), the other enables/disables the hardware PFC.

3.1.11 PTC Relay

This output enables/disables the PTC pre-charge circuit for the DC bus. The PFC is enabled when the PTC pre-charge circuit is switched out and the bus is considered started.

3.1.12 Non-Volatile Memory (Serial EEPROM)

There are several pieces of information stored by the DSP in non-volatile memory. The following is a listing of that data.

Table 1. EERPOM Memory Map

Item	Default Value	Notes
CHECKSUM	0	Not implemented
DATA_FORMAT_VERSION	12	Current Data Format Version
WATER_PRESSURE_SETPOINT	45	45 PSI
LOW_BAND_PRESSURE	1	1 PSI
HIGH_BAND_PRESSURE	4	4 PSI
BUS_CURRENT_HIGH_LIMIT	150	15.0 Amps
OVER_TEMPERATURE	70	70 C
AUX_RELAY_MODE	0	Relay Disabled
PROPORTIONAL_GAIN	80	Default Gain, Changed by RCal
INTEGRAL_GAIN	18	Default Gain, Changed by RCal
BUS_CURRENT_LIMP_LIMIT	70	7.0 Amps
BUS_VOLTAGE_HIGH_LIMIT	450	450 Volts
BUS_VOLTAGE_LOW_LIMIT	250	250 Volts
LIMP_TEMP_LIMIT	60	60 C
HIGH_MOTOR_FREQ_LIMIT	80	80 Hz
VHZ_RATED_VOLTAGE	250	250 VAC RMS
DRY_RUNNING_CURRENT_LIMIT	15	1.5 Amps (from DC Bus)
DRY_RUNNING_TIME_LIMIT	100	1.00 seconds
VHZ_RATED_FREQ	65	65 Hz
VHZ_OFFSET_VOLTAGE	10	10 VAC RMS
MIN_OPERATING_SPEED	12287	about 30 Hz (30-80Hz Motor)
AUX_RELAY_MIN_ONTIME	50	500 ms
AUX_RELAY_MIN_OFFTIME	50	500 ms
AUX_RELAY_OFF_DEBOUNCE	50	500 ms
CONFIG_SWITCH_AT_LAST_CAL	65534	Bogus value; first position saved
LINE_CURRENT_LIMP	260	26.0 Amps
BUS_VOLTAGE_LIMP	275	275 Volts
Powered Time	0	Reset by Default
Running Time	0	Reset by Default
Fault Log Indexes	0	Reset by Default
Fault Log	0	Reset by Default

3.1.13 Serial Communications with 8-Bit processor

The DSP and the 8-bit processor communicate over an optically isolated asynchronous communication channel using the following protocol.

There are 4 bytes of control data passed between the two processors at a 64Hz interval. No error detection or correction mechanisms are in place on this channel.

The HyperTerminal data is also transferred to the DSP via the 8-bit processor. This data is limited to ASCII printable standard characters and is interleaved with the control data. The MSB of the data byte being set identifies control data packets.

3.1.13.1 Communication DSP-to-PIC Detailed

The communication protocol information breaks down as follows; baud rate 38400 baud, 8-N-1, Software flow control. (Xon/Xoff can be supported based on build options at both the DSP and 8-bit processor)

General Data Format

Data Flag	Hi/Lo "Byte"	Channel 0 = Press. 1 = Run/Stop	Data	Data	Data	Data	Data (variable)
7	6	5	4	3	2	1	0

Data Explained
(note: data format transfers only the upper 9 bits of the 10 bit ADC)

1	0	0	D4, Press	D3, Press	D2, Press	D1, Press	D0, Press
7	6	5	4	3	2	1	0

1	1	0	D9, Press	D8, Press	D7, Press	D6, Press	D5, Press
7	6	5	4	3	2	1	0

1	0	1	D4, Temp	D3, Temp	D2, Temp	D1, Temp	Run/ Stop Status
7	6	5	4	3	2	1	0

1	1	1	D9, Temp	D8, Temp	D7, Temp	D6, Temp	D5, Temp
7	6	5	4	3	2	1	0

Example Transmission:

Pressure ADC Data	500	(0x01F4)
Temperature ADC Data	201	(0x00C9)
Run/Stop	0	(1 = On, 0 = Off)

1	0	0	1	0	1	0	0
7	6	5	4	3	2	1	0

1	1	0	0	1	1	1	1
7	6	5	4	3	2	1	0

1	0	1	0	1	0	0	0
7	6	5	4	3	2	1	0

1	1	1	0	0	1	1	0
7	6	5	4	3	2	1	0

3.1.13.2 Supported Serial Commands

A serial communications interface is provided to allow for configuring drive parameters and reading drive status. This allows an external device, such as a PC, laptop or PDA, to talk to the drive using a terminal program, such as Windows HyperTerminal. The parameters for serial communications are 9600-baud, 8 data bits, no parity, 1 stop bit and XON/XOFF flow control.

Many commands for the serial communications are defined. Commands are identified by four capital letters. If the command is a "set" command, a numeric parameter follows the command. All characters are in ASCII format.

Table 2. Serial Command Summary

Description	Command	NOTES
Run Drive	RCMD	Put the drive in run mode.
Stop Drive	STOP	Put the drive in stop mode.
Get Version	GVER	Get number of the DSP software programmed
Fault History	GFLT	Get the all fault codes with time stamps

Parameter Lists	DCPS	Display control parameters: Pressure Setpoint Proportional Gain Setting Integral Gain Setting Calibrated Minimum Operating Speed
	DOPD	Display operational parameter data: Drive Enabled/Disabled Status Run/Stop Input Status Fault Status Limp Status Water Pressure Heatsink Temperature Drive Speed Bus Voltage Bus Current Input Power Output Power (includes 0.97 adjustment for drive bridge efficiency) Motor Run-Time (in minutes)
	DOPR, DATA	Continuously display the DOPD data.
Display Frequency	GFRQ	Display the current drive frequency
Display Pressure	GPRS	Display the current system water pressure
Pressure Set Point	GPSP, SPSP	Display/Set the Target water pressure value (in EEPROM) Note: Pressure Set Point Switch must be set to zero for this item to be active. Range: 25-95
Display Run/Stop Switch Status	GRSS	Display the Run/Stop input switch status.
Display Input Voltage	GLNV	Display the Input Line Voltage (RMS)
Display Input Current	GLCR	Display the Input Line Current (RMS)
Display Input Power	GIPR	Display the Input Power (VA)
Display Output Power	GOPR	Display the Power Supplied to the Motor (VA)
Display Powered Time	GPTM	Displays the time in minutes since the last power cycle.
Display Running Time	GRTM	Displays the time in minutes the motor has run. Stored to EEPROM when one hour of run-time has accumulated since the last time it was stored.
Bus Voltage	GBSV	Display the current Bus Voltage
	GBVL, SBVL	Display/Set the Bus Voltage Lower Limit Range: 250-320 VDC
	GBVU, SBVU	Display/Set the Bus Voltage Upper Limit Range: 321-450 VDC
Bus Current	GBCR	Display the Bus Current
	GBCU, SBCU	Display/Set the Bus Current Upper Limit Range: 1-250 (Corresponds to 0.1 to 25.0 Amps)
Heat Sink Temperature	GTMP	Display the current Heat Sink Temperature (in °C)
	GTUL, STUL	Display/Set the High Temperature Limit Range: 1-125 (Degrees Celsius)

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Auxiliary Output Relay	GARM, SARM	Display/Set mode for the Auxiliary Relay. Mode 0 forces the relay off. Mode 1 turns the relay on with the motor.
	GARP, SARP	"GARP0" Get/Set minimum on time in 10ms units. "GARP1" Get/Set minimum off time in 10ms units. "GARP2" Get/Set off debounce time in 10ms units.
	GARS	Display Auxiliary Output Relay Status.
Motor Type Switch Setting	GMSS	Display the motor type switch setting.
Pressure Setting Switch Status	GPSS	Display the pressure setpoint switch PSI setting.
Low Band Pressure	GLBP, SLBP	Display/Set the Low Pressure Band Limit Range: 1- 10
High Band Pressure	GHBP, SHBP	Display/Set the High Pressure Band Limit Range: 1- 10
Dry Running	GDRT, SDRT	Display/Set Dry Run Time. Range: 0-900 (0 to 9.00 seconds)
	GDRC, SDRC	Display/Set Dry Run Current. Range: 0-70 (corresponds to 0-7.0 amps)
Run Pressure Calibration	RCAL	Force the Drive to Run the Min. Speed Calibration
Proportional Gain	GGKP, SGKP	Display/Set the PI controller's P gain term. Range of 0 to 999.
Integral Gain	GGKI, SGKI	Display/Set the PI controller's I gain term. Range of 0 to 999.
Calibrated Minimum Speed	GCMS, SCMS	Display/Set the calibrated minimum speed. Range: 0 to 32767.
V/HZ Settings	GVRF, SVRF	Display/Set the Rated Motor Freq. Range 30-200 (Hz)
Motor select switch must be in position 0	GVMF, SVMF	Display/Set the Max. Motor Freq. Range 30-250 (Hz)
Reset required for changes to take affect	GVRV, SVRV	Display/Set the Rated Motor Volts. Range 20-250 (VAC RMS)
	GVOV, SVOV	Display/Set the Motor Offset Voltage. Range 0-40 (VAC RMS)
Limp Thresholds	GBLC, SBLC	Display/Set Bus Limp Current. Range: 1-250 (Corresponds to 0.1 to 25.0 Amps)
	GLTL, SLTL	Display/Set Limp Temperature. Range: 1-125 (Degrees Celsius)
	GLLC, SLLC	Display/Set Limp Line Current Range: 0-400 (Corresponds to 0.0 to 40.0 Amps RMS)
	GBLV, SBLV	Display/Set Bus Limp Voltage. Range: 0-450 VDC
Software Reset	SRST	Commands the system to perform a software reset, Drive must be disabled
Default EEPROM	DFEE	Commands the system to default the EEPROM. Drive must be in stop mode, the Run/Stop input must be inactive and the Alarm Reset Pushbutton must be Active. Unit will reset after the Alarm Pushbutton is released.

NOTE 1: Parameters set by the motor select switch may not be changed via the serial link unless the motor select switch is set to position 0. These parameters include: V/Hz settings, shutdown bus current, limp bus current and dry running current setpoints. Commands to retrieve V/Hz settings (GVRF, GVMF, GVRV and GVOV) will return the failure string if the motor select switch is not set to position 0. The other affected commands will return the appropriate values for the selected motor.

NOTE 2: The pressure setpoint may only be changed via the serial link when the pressure selection rotary switch is in position 0.

NOTE 3: When changing the V/Hz settings via the serial link, changes will not take effect until following a system reset (power cycle or SRST command).

3.1.14 Pulse Width Modulated Outputs

Six PWM channels are required for controlling the Inverter that supplies 3-phase power to the motor. The PWM waveforms are Symmetric and are operated in a manner consistent with space vector modulation firing sequences. The event manager peripheral on the TI DSP controls all the PWM outputs as well as their dead band timers.

3.2 Inputs Sampled with 8-bit Processor

To facilitate hardware isolation, an external 8-bit microcontroller, specifically a Microchip PIC16LF870 (or PIC), is used to read certain analog inputs and to handle serial communications.

The analog inputs the PIC reads are the pressure transducer, heat sink temperature sensor, the run/stop switch and the isolated power supplies for the two pressure transducer types. These analog inputs are described in the Analog Inputs section above. The PIC reports this information to the DSP at uniform time intervals.

The baud rate between the PIC and an external device is 9600 baud.

The DSP commands the external microcontroller to enter its "normal" mode once per second. This is necessary in case the external microcontroller might reset with out the DSP being reset. See the STA-RITE PIC Firmware Architecture document for details of "normal" mode.

3.2.1 4-20 mA Pressure Sensor Feedback

4-20 mA Pressure Sensor Feedback is used to modify the commanded motor speed in order to maintain a constant water pressure. A 0-5 VDC pressure sensor can optionally be used in place of this sensor. The PIC software automatically determines which pressure sensor is connected. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz. The range for this input is 0 to 100 PSI.

3.2.2 0-5 VDC Pressure Sensor Feedback

0-5 VDC Pressure Sensor Feedback is used to modify the commanded motor speed in order to maintain a constant water pressure. A 4-20 mA pressure sensor can optionally be used in place of this sensor. The PIC software automatically determines which pressure sensor is connected. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz. The range for this input is 0 to 100 PSI.

3.2.3 4-20 mA Sensor Check

4-20 mA Sensor Check is used to verify there is not a fault on the 4-20 mA pressure sensor. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz.

3.2.4 0-5 VDC Sensor Check

0-5 VDC Sensor Check is used to verify there is not a fault on the 0-5 VDC pressure sensor. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz.

3.2.5 Heat Sink Temperature

Heat Sink Temperature is used to halt motor operation during an over-temperature condition. The maximum frequency of this input is 8 Hz, so the minimum sample rate is 64 Hz. The range for this input is -25°C to +140°C.

3.2.6 Run/Stop Input

The Run/Stop input is used to enable/disable the drive. The drive is enabled when the input is active (contacts closed). Conversely, the drive is disabled whenever the input is inactive.

3.3 Motor Control for Constant Water Pressure

Constant water pressure is maintained in the pump/tank/distribution system by constantly monitoring actual water pressure and comparing it with the desired water pressure. There is a small hysteresis band around the desired water pressure setpoint. The high band pressure is defaulted to 1 PSI greater than the setpoint, and the low band pressure is defaulted to 1 PSI lower than the setpoint. The high and low band pressures are configurable and stored in EEPROM.

For the case where the pump motor is off (not being driven), the water pressure is monitored but no action is taken until the pressure falls below the low band pressure. Once the pump motor starts spinning, normal operation with PI control commences and continues until the water pressure exceeds the high band pressure, or the PI control output is zero.

For normal operation, with the motor spinning, the controller will regulate pump speed in a continuous fashion using the PI control loops as long as the pressure remains below the high band pressure value. The motor drive will be set to zero whenever the actual pressure exceeds the high band pressure value. During normal operation, as long as water usage does not exceed the motor/pump capabilities, the pressure will remain constant at a value very close to the desired water pressure setpoint. Large instantaneous changes in flow requirements may result in variations from the desired pressure band.

System performance parameters include low pressure undershoot and low pressure recovery time for instances of increased flow and high pressure overshoot for instances of decreased flow (including zero flow). Because the control system does not have control of water usage and the pump can only supply positive flow, in cases where the flow is reduced very rapidly or halted, the high pressure recovery time is not meaningful.

System performance requirements are to meet or exceed the performance of a specific competitor's system. This performance is documented in ***Performance Testing of Franklin Drive at Sta-Rite Facility***, dated January 14, 2002. More details regarding the testing procedures can be found in document ***Performance Criteria Laboratory Investigation for Sta-Rite High Speed Controller***, dated December 12, 2001.

3.3.1 PI Controller

During normal operation with the motor spinning and the water pressure below the high band pressure, Proportional/Integral (PI) control is implemented to maintain pressure at the desired pressure setpoint. The input to the PI controller is the pressure error signal, which is found by subtracting the actual water pressure from the desired pressure setpoint. The output of the PI controller is a value representing motor drive frequency. The proportional component of the PI controller output is found by multiplying the pressure error by a proportional gain. Integrating the pressure error and multiplying the result by an integral gain determines the integral component of the PI controller output. The overall PI controller output is then just the sum of the proportional and integral components.

Integral control is included in the design in order to provide zero steady state error. In other words, if the motor is spinning and the pump is providing flow, the pressure can be exactly the desired pressure setpoint and the motor will continue to operate. With a proportional only control system, the control is error driven in the sense that there must be some error to generate a nonzero proportional output. Thus, in cases where the motor and pump are spinning and supplying some flow, a proportional only controller would always result in slightly low water pressure.

In order to provide high performance control, it is necessary to take into account the motor speed required for the pump to actually open the check valve and produce positive water flow from the pump. This minimum motor speed to produce flow will be referred to here as minimum nonzero flow speed. The actual motor command is the sum of this minimum nonzero flow speed and the output from the PI control algorithm. This combination ensures that small pressure errors are capable of turning on the motor, which allows accurate pressure regulation for low flow cases as well as rapid response for large transient increases in flow demand.

The pump motor frequency will be set to zero for two cases. First, as described above, whenever the water pressure exceeds the high band pressure the output to the motor will be ramped to zero. Secondly, when the pressure setpoint has been reached and no flow is occurring, the PI controller will have a very small output. When the PI controller output falls below a certain value, the motor output will be set to idle speed for 10 seconds. Idle speed is a speed below the minimum nonzero flow speed and is intended to keep the motor spinning without opening the check valve and causing water flow from the pump. During the 10 second idle time, if new demand for flow occurs, the control automatically switches from idle mode to normal pressure regulation mode. For these transitions, the motor is already running at a speed near the minimum nonzero flow speed, allowing very fast flow response compared to starting the motor from zero speed. After running at idle speed for 10 seconds without a drop in pressure (demand for flow), the motor speed will be ramped to zero.

3.3.2 Minimum Nonzero Flow Speed Calibration Routine

The minimum nonzero flow speed discussed above is a function of the motor, the pump, and the total head pressure at the pump, which is a function of the pressure tank setpoint and the well depth. Obviously, these parameters will be different from one system to another, yet the controller needs to provide excellent performance regardless of the installation particulars. As such, it is necessary to determine the minimum nonzero flow speed for each application.

A calibration routine is used to determine the minimum nonzero flow speed. Calibration assumes that all user valves are shut and the tank pressure is at or below the pressure setpoint. If the tank pressure is above the setpoint when calibration is invoked, the calibration routine waits until the tank pressure is reduced to a value below the pressure setpoint, and then waits 5 additional seconds during which time the flow must be shut off. Water flow out of the system during the rest of the calibration procedure may result in inaccurate calibration results.

After ensuring that the pressure is at or below the pressure setpoint and assuming that the flow is zero, the calibration enters a pressure regulation mode to raise the tank pressure to the desired pressure setpoint. Once the tank pressure has been raised to the proper level, or if the tank pressure is already at the desired pressure setpoint when the regulation mode of the calibration routine is entered, the calibration routine proceeds to the next calibration mode.

After successful pressure regulation, the search pressure is determined by adding 1 PSI to the current tank pressure. The calibration routine then enters search mode. In search mode the motor starts at the minimum operating speed for that motor and slowly increases motor speed until the tank pressure exceeds the search pressure. In other words, the search mode ends when the motor is spinning at or above the minimum nonzero flow speed, causing flow into the tank to raise the tank pressure.

When finished with search mode, the controller stores the minimum nonzero flow speed (also referred to as the calibrated minimum operating speed) in EEPROM and computes the idle speed. The actual pressure regulation PI feedback gains are also set at this time, based on the minimum nonzero flow speed, via a lookup table which is filled with empirical values obtained via lab testing.

Calibration is invoked automatically whenever the drive is powered up with a new pressure setpoint. At power up, the system checks to see if the current pressure setpoint is the same as the previous pressure setpoint, which is stored in EEPROM. In an ideal case, the calibration routine will run only once after the very first installation. The calibration routine can also be invoked through the use of the serial communication link. When changing the pressure setpoint via the serial link, calibration should always be invoked by the user and is an important responsibility of the user for serial-communication-aided system configuration.

Calibration is also automatically invoked whenever the drive is powered up with a new selection on the motor selection switch. If the motor selection is set to custom (parameters set via the serial link), the user should invoke the calibration procedure manually whenever motor parameters are updated.

3.3.3 Space Vector PWM

The 3-phase induction motor is driven using the Space Vector Pulse Width Modulation (SV PWM) technique. In this technique, the commanded drive frequency is converted to an angular value via numerical integration. This angular value is combined with the desired output voltage level in order to provide the pulse timings for the 3-phase power converter. The output of the system provides precise control of the magnitude and angle for the stator electromagnetic field of the AC induction motor.

A much more in depth discussion of the SV PWM technique can be found in ***AC Induction Motor Control Using Constant V/Hz Principle and Space Vector PWM Technique with TMS320C240***, Application Report SPRA284A, by Zhenyu Yu and David Figoli (TI DSP Digital Control System Applications).

3.3.4 Volts/Hertz Curves

As stated above, SV PWM techniques combine an angular value with a voltage level, which is a function of the speed of the motor. The angular value is determined by integrating the commanded drive frequency. The voltage is calculated by using a Volts/Hertz (V/Hz) curve that directly determines the voltage based only on the drive frequency. The shape of the V/Hz curve is motor dependent and can usually be determined from the motor speed and voltage ratings. This technique is simple and effective for most speed control applications involving AC Induction motors.

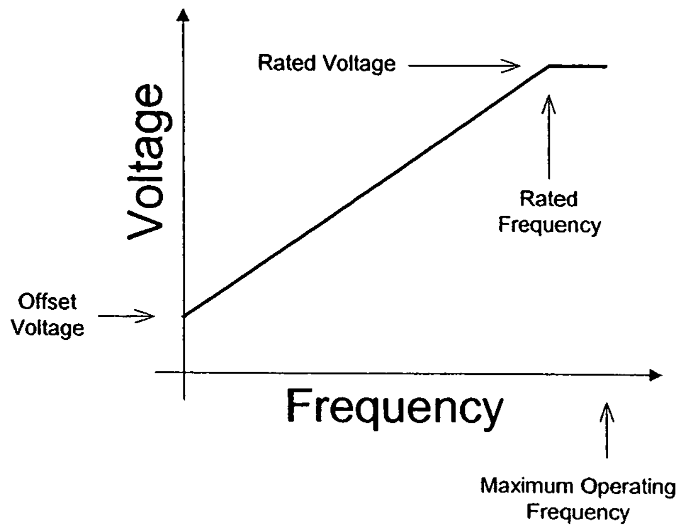
The V/Hz curves will be implemented via a first order curve with an upper limit and an offset term. A second order curve may be implemented after testing to optimize system performance. As such, for each V/Hz curve, several parameters are stored. The parameters include: slope, rated (maximum) voltage, and offset voltage for the V/Hz curve, as well as maximum and minimum operating motor frequencies. The slope value is calculated based on offset voltage as well as rated voltage and frequency. It is not directly user programmable.

The software will support three default and one custom V/Hz curves. The three default V/Hz curves are not user programmable. Only the custom V/Hz curve is user programmable via serial commands. The Motor Select Switch is used to select which V/Hz curve is active.

The first default curve is a 30-60 Hz curve that provides operational frequencies from 30 Hz to 60 Hz, with maximum voltage occurring at 60 Hz. For this motor, the rated frequency and the maximum frequency are identical at 60 Hz. The second default curve is a 30-80 Hz curve that is intended to run the Franklin motor. This curve has a rated frequency of 65 Hz but a maximum frequency of 80 Hz, meaning that between 65 and 80 Hz, the output voltage is held constant at the maximum value. The third default curve is a 30-200 Hz curve that provides maximum voltage at 200 Hz, the rated and maximum frequencies.

For the custom V/Hz curve, the user can specify the curve over the serial user interface with four parameters. The four parameters are offset voltage, rated frequency, rated voltage, and maximum frequency.

3.3.5 Programmable Volts/Hertz Curve



The V/Hz curve is defined by 4 parameters, with 2 of the parameters (Rated Voltage and Rated Frequency) usually being displayed on the motor itself.

Most motor manufacturers supply the offset voltage when they supply a V\Hz curve for their motor. This offset voltage is necessary to produce the rated flux (and hence the rated torque) and is dependent on the stator winding resistance and the rated magnetizing current. At speeds greater than the Rated Frequency, the output voltage will remain at the Rated Voltage and the torque will decrease due to field weakening. Setting the Maximum Operating Frequency to a value higher than the Rated Frequency should only be done in cases where the motor is not fully loaded at the Rated Frequency (i.e. does not use full rated torque).

3.3.6 Soft Start

When the motor is started up from a stopped state, a "Soft Start" algorithm is used. The soft start algorithm is defined as accelerating the motor from 0 to 30 Hz within 1 second. This requirement comes from the self-lubrication specification for the pump.

3.3.7 Soft Stop

When the motor is commanded to stop while in a running state, a "Soft Stop" algorithm is used. The soft stop algorithm is employed whenever the commanded drive frequency is below 30 Hz. In this case, the voltage to the motor is ramped to 0 volts as quickly as possible without causing motor regeneration. To prevent rapid cycling when the water demand is slightly less than the minimum flow rate of the pump for a given pressure tank size and well depth the control is allowed to idle at a minimum operating speed for 10 seconds after the target pressure is reached and the water demand has stopped. This mitigates constant on/off cycling of the water pump system during times of low water demand (example leaks).

3.4 Limp Mode

In general when limp mode is active the output voltage and frequency supplied the motor are reduced, along the V-Hz curve for that motor, in an attempt to prevent catastrophic failure and keep the drive operating within acceptable operational limits. Limp mode entry is not record in the fault log. In addition, it is probable that pressure regulation will not be maintained during the time that a limp mode is active. Typically, if limp mode is active rated outputs cannot be achieved. Three events can trigger entry into Limp mode.

3.4.1 Limp on High Bus Current

If the bus current exceeds the limp current limit setting, the drive enters the limp current mode.

3.4.2 Limp on Low Bus Voltage

The DSP software monitors the bus voltage. The drive enters the limp mode if the bus voltage falls below the programmed threshold.

3.4.3 Limp on Input Current

The DSP software monitors the line current. The drive enters the limp current mode if the line current exceeds the programmed threshold.

3.4.4 Limp on High Temperature

If the heat sink temperature exceeds the limp temperature limit setting, the drive enters limp mode.

3.5 Fault Detection

The controller detects certain fault conditions and attempts to prevent damage to itself and/or the motor. The following section describes each fault, the condition under which it occurs, and the action that is taken after sensing the fault.

The 15 most recent fault conditions will be stored in the EEPROM as codes. See the Fault Codes section below for a listing of faults and their corresponding code. A fault code is stored along with a time stamp of the current powered time (time since last power up) when the fault was logged.

Fault Code	Fault Name
00	NO FAULT
01	BUS OVER VOLTAGE
02	BUS UNDER VOLTAGE
03	OVER CURRENT
04	DRY RUNNING
05	OVER TEMPERATURE
06	PRESSURE SENSOR FAILURE
07	POWER DEVICE / GROUND FAULT
08	PRESSURE SENSOR FAILURE
09	JAM DETECTED
10-98	Reserved
99	NO FAULT

3.5.1 DC Bus Over Voltage

A bus over voltage fault occurs when the bus voltage is greater than the bus voltage upper limit. At the detection of this fault condition, the drive is shutdown for 30 seconds. After 30 seconds, the drive attempts to restart.

3.5.2 DC Bus Under Voltage

A bus under voltage fault occurs when the bus voltage is less than the bus voltage upper limit. At the detection of this fault condition, the drive is shutdown for 30 seconds. After 30 seconds, the drive attempts to restart.

3.5.3 Bus Over Current

A bus over current fault occurs when the bus current is greater than the bus current upper limit setting. At the detection of this fault condition, the drive is shutdown for 30 seconds. After 30 seconds, the drive attempts to restart.

3.5.4 Dry Running

A dry running fault occurs when the current drawn from the DC bus is below a pre-set threshold based on the motor, for a preset time while the drive is running at full speed. At the detection of this fault condition, the drive is shutdown for 30 seconds. After 30 seconds, the drive attempts to restart.

3.5.5 Over Temperature

An over temperature fault occurs when the temperature of the heat sink is greater than the temperature upper limit. At the detection of this fault condition, the drive is shutdown. The drive attempts to restart only after the heat sink temperature has dropped below the "Limp" temperature limit.

3.5.6 Foreign Object Jamming Pump

A foreign object jamming pump fault occurs for two related conditions. When a jam occurs at high motor speed, the current rises rapidly and a bus over current fault occurs. When a bus over current fault occurs five times within five minutes, a jam condition is assumed. The second technique detects a jam condition at low/zero motor speeds. At startup, if the pump is jammed the current will be unusually high at low speeds. High currents at low speeds will invoke the current limp protection feature. If current limping is enabled at exceptionally low speeds, a jam is assumed.

At the detection of this fault condition, a jam recovery process is entered. For jam recovery, the drive tries to run the motor in the reverse direction for 30 seconds. If the motor runs in reverse for 30 seconds, it is assumed that the pump is cleared and the drive attempts to run the motor in the forward direction. If a jam is detected in reverse as well, the controller logs the fault and shuts the controller down until power is cycled.

3.5.7 Pressure Sensor Failure

A pressure sensor failure fault occurs when the signal from pressure sensor is outside the sense range. At the detection of this fault condition, the drive is shutdown. This failure is ignored after power-up until a sensor is first detected. The drive remains in this mode until a sensor is connected. The detection algorithm for this fault is flexible such that it is able to handle pressure sensors that supply either a 4-20 mA, or a 0-5 VDC output.

A pressure sensor failure also occurs when the sensor power supply is detected to be shorted. Upon detection of this failure, the sensor power supply is disabled. If the shorted sensor supply is the selected sensor input, the drive is shutdown. If the non-selected sensor input supply is shorted, the power supply is disabled; however, the failure condition is ignored.

3.5.8 Power Device / Ground Fault

A power device / ground fault occurs when the PDPINTA input has been asserted. At the detection of this fault condition, the drive is shutdown. The drive is allowed to restart after 30 seconds. The third PDPINTA event since last power up forces the drive into an off condition and only a power cycle can cause this error to clear.

3.6 Fault Handling and Logging

The 15 most recent faults are stored in non-volatile memory. As a fault is logged, the current powered time value is logged with the fault. When there are 15 faults in the log, then the software overwrites the oldest fault with any new fault.

If no faults have occurred since the last reset (either power cycle or clear faults button press), the controller keeps the Red LED in the de-energized state. However, blinking the Red LED at various rates, depending on the fault group, which the most recent fault is in, provides indication of faults. However, the exception is the Red LED is solid on if too many faults occur within a set time period.

After any fault that stops the motor, with the exception of over temperature, power device / ground fault, and pressure sensor faults, the controller waits 30 seconds and then attempts a restart.

If 15 faults occur within 30 minutes, the controller will shutdown and turn the Red LED solid on. Upon power up or a clear faults button press, the controller will reset the fault counter and the fault clock. When any fault occurs, if the fault clock is greater than 30 minutes, the clock is reset to zero.